

REMOVAL OF THIOETHIONYLFLUORIDE FROM SULFUR TETRAFLUORIDE

BACKGROUND OF THE INVENTION

5 This invention relates to providing pure sulfur tetrafluoride (SF_4). More particularly, it relates to the removal of thioethionylfluoride ($\text{S}=\text{SF}_2$) from SF_4 by contacting the impure SF_4 with a high surface area material, such as activated carbon.

Sulfur tetrafluoride is an extremely useful fluorinating agent, which is particularly suited for the fluorination of oxygen-, sulfur- and nitrogen-containing groups bonded to non-metal or metal atoms. See, e.g., U.S. Patent No. 3,950,498 to Appel et al. According to a publication of Air Products and Chemicals, Inc. (<http://www.airproducts.com/fluorination/-sulfur.asp>; 2001), SF_4 is particularly useful for deoxofluorinating aldehydes, ketones and carboxylic acids in the presence of hydrogen fluoride (HF) and other Lewis acid catalysts.

10 SF_4 can be produced by a variety of methods. For example, U.S. Patent No. 2,992,073 to Tullock describes a process for producing SF_4 comprising reacting an alkali metal fluoride (wherein the alkali metal is Na, K, Rb or Cs) with a chlorine-supplying reactant (e.g., elemental Cl, etc.) and sulfur-supplying reactant (e.g., elemental S, etc.).

15 U.S. Patent No. 3,950,498 to Appel et al. describes a process for the production of sulfur tetrafluoride, wherein sulfur tetrachloride or mixtures consisting of sulfur dichloride and chlorine are reacted with hydrogen fluoride in the presence of a carbon tetrahalide to provide SF_4 .

20 A problem with existing methods for manufacturing SF_4 is the production of undesirable byproducts that contaminate the SF_4 . Such impurities can hinder the usefulness of SF_4 as a fluorinating agent.

25 Thioethionylfluoride is a particularly undesirable SF_4 contaminant. Thioethionylfluoride is typically observed in SF_4 compositions at concentrations of 5% or more. Although

thermally stable, $\text{S}=\text{SF}_2$ can undergo a disproportionation reaction to produce elemental sulfur when using SF_4 as a raw material. The elemental sulfur byproduct can interfere with the SF_4 chemistry and foul the processing systems.

Seel, "Lower Sulfur Fluorides" in 16 *Adv. Inorg. Chem. Radiochem*, 297, 303-304 (1974), describes a process for converting pure $\text{S}=\text{SF}_2$ to SF_4 and elemental sulfur using catalysts, such as HF or BF_3 . Although Seel does not address the problem of removing $\text{S}=\text{SF}_2$ from SF_4 , the inventor is aware of a proprietary process for removing $\text{S}=\text{SF}_2$ from SF_4 , which employs the same chemistry as described by Seel to disproportionate $\text{S}=\text{SF}_2$ to form S_8 and SF_4 using HF (or BF_3). However, this process is both inefficient and dangerous because it causes significant losses of SF_4 and requires using large quantities of HF. The HF catalyst becomes deactivated during the disproportionation, because of the formation of the salt $\text{SF}_3^+\text{HF}_2^-$ (BF_3 catalyst becomes deactivated by formation of the analogous salt with SF_4). Thus, in order to have sufficient free HF present to initiate the disproportionation of $\text{S}=\text{SF}_2$, at least 30 mole% of HF must be mixed with the contaminated SF_4 . While this method produces SF_4 free of impurities, about 20-25% of the SF_4 is unrecoverable from the HF. The proprietary process is dangerous in that it involves handling large quantities of liquid anhydrous HF. HF is a gas under standard conditions, and reacts violently with many materials including glass. It can permeate large areas rapidly, and is extremely dangerous to humans. It is, therefore, desirable to avoid handling large quantities of HF.

The use of high surface area materials, such as activated carbon, zeolites, and silica, for separation processes is known. However, the inventor is not aware of any prior art disclosing the use of high surface area materials for removal of $\text{S}=\text{SF}_2$ from SF_4 .

Accordingly, it is desired to provide a safer and more efficient process for removal of $\text{S}=\text{SF}_2$ from SF_4 .

All references cited herein are incorporated herein by reference in their entireties.

BRIEF SUMMARY OF THE INVENTION

The invention provides a process for removing thiotionylfluoride from a composition containing sulfur tetrafluoride and an initial concentration of thiotionylfluoride. The process comprises: contacting the composition with an activated carbon; reacting at least a portion of the thiotionylfluoride to form elemental sulfur; and recovering a purified composition containing the sulfur tetrafluoride and the thiotionylfluoride at a reduced concentration less than the initial concentration.

Also provided is a process for removing thiotionylfluoride from a composition containing sulfur tetrafluoride and an initial concentration of thiotionylfluoride, which process comprises: contacting the composition with a metal oxide-free material having a surface area of at least 400 m²/g; reacting at least a portion of the thiotionylfluoride to form elemental sulfur; and recovering a purified composition containing the sulfur tetrafluoride and thiotionylfluoride at a reduced concentration lower than the initial concentration.

DETAILED DESCRIPTION OF THE INVENTION

The inventive process comprises the use of a high surface area material for removing thiotionylfluoride from a composition containing sulfur tetrafluoride and thiotionylfluoride. As used herein, the term "high surface area material" means materials having a surface area of at least 400 m²/g. Preferred high surface area materials of the invention have a surface area of about 800 to about 1000 m²/g.

The most preferred type of high surface area material is activated carbon, particularly activated carbon having a minimum number of oxygen-containing active sites. Depending on how the carbon is activated, activated carbon possesses varying amounts of oxygen at active sites, usually in the form of carboxyl, carbonyl, or hydroxyl groups. These functional groups will also react with SF₄ to produce SO₂ or SOF₂. Thus, the preferred activated

carbons (and high surface area materials in general) are those with the least amount of oxygen-containing active sites.

In the absence of any readily available direct analysis to quantify oxygen-containing active sites on activated carbon, relative comparisons can be made between different activated carbons. The relative quantity of oxygen-containing sites can be determined by SO_2 and SOF_2 produced upon exposure to SF_4 and the relative capacities for $\text{S}=\text{SF}_2$ can be measured by column experiments. If two activated carbons are equivalent in amount of oxygen-containing active sites, then the carbon with the greater surface area will be preferred.

While high surface area materials other than activated carbon promote the disproportionation of $\text{S}=\text{SF}_2$ to S_8 and SF_4 , the material used in the inventive process must be compatible with SF_4 . The use of activated carbon is preferred because it does not react with SF_4 . It is preferred to avoid employing high surface area materials containing metal oxides, such as alumina or zeolites, as such materials react with SF_4 to form SO_2 or SOF_2 .

The high surface area material can be brought in contact with the composition to be purified by a variety of means. In a preferred embodiment, the material is provided in the form of a bed in a column (preferably stainless steel) through which the composition to be purified is passed.

The capacity of high surface area materials to remove thiothionylfluoride from sulfur tetrafluoride varies, but can be determined through routine experimentation using the instant disclosure as a guide. In preferred embodiments, a maximum of 800 grams, more preferably, 150 grams of the material are provided per mole of the thiothionylfluoride being reacted to form elemental sulfur and sulfur tetrafluoride through the disproportionation reaction.

The composition to be purified (typically, but not necessarily, containing at least 8% v/v thiothionylfluoride) is contacted with the high surface area material, for example in a

column as noted above, and the resulting effluent is collected and monitored for the presence of sulfur tetrafluoride and/or thiosthionylfluoride. The presence of thiosthionylfluoride in the effluent is preferably detected by monitoring the ultraviolet absorbance at 240 nm and/or 290 nm. FT-IR is preferably used to detect the presence of other potential impurities, such as SO₂ and SOF₂, and to determine the time to SF₄ breakthrough. A purified composition completely free of thiosthionylfluoride can be obtained by collecting only those fractions of the effluent that do not emit signals indicative of thiosthionylfluoride.

The flow rate of the composition to be purified is 0.1 to 5, more preferably 0.4 to 1 lb-mole/ft²/hr.

As the process is conducted, the effectiveness of the high surface area material is depleted. In particular, elemental sulfur from the disproportionation reaction is deposited on the high surface area material, requiring that the material be replaced or regenerated. The material can be regenerated by contacting the material with a gas mixture containing oxygen and nitrogen to convert elemental sulfur adsorbed to the material to sulfur dioxide without oxidation of the material. The gas mixture preferably comprises 1 to 21 vol.% oxygen and 79 to 99 vol.% nitrogen. More preferably, the gas mixture is air. The gas mixture is preferably provided at a temperature of 250-300°C and a flow rate so as to maintain an oxidation rate such that a reaction zone temperature does not exceed 400°C. In embodiments, the oxidation rate is maintained at 9-1000 µg/min. It is preferred to purge volatile adsorbed species from the spent material with inert gas prior to conducting the regeneration process. Preferred inert gases include the noble gases, nitrogen and carbon dioxide, with nitrogen gas and argon gas being most preferred.

The invention is illustrated below in more detail with reference to the following examples, but it should be understood that the present invention is not deemed to be limited thereto.

Example 1

Removal of S=SF₂ from SF₄ using Pacific Activated Carbon

A 2.8 cm (internal diameter) x 37 cm stainless steel column (0.23 L) was filled with 104 g of Pacific activated carbon. The column was heated externally in two zones with resistive heat tape to an internal temperature of 150°C under 0.5 standard liters per minute (sLpm) N₂ flow for 15 hours to activate the carbon. The column was cooled to room temperature and SF₄ containing 8% v/v S=SF₂ was passed through the column. The S=SF₂ concentration was monitored by UV ($\epsilon_{240\text{nm}} = 515 \text{ L/mol/cm}$, $\epsilon_{290\text{nm}} = 128 \text{ L/mol/cm}$) with a 10 cm path cell. The stream was also monitored by FT-IR for detection of other potential impurities, such as SO₂ and SOF₂, and to determine the time to SF₄ breakthrough on the column. After 3.5 sL of SF₄ were introduced on the column, SF₄ free of S=SF₂ was observed in the effluent from the column, along with small amounts of SOF₂ and SO₂. After 10 sL of SF₄ were introduced on the column, SOF₂ and SO₂ were no longer observed. After 160 sL of SF₄ had been purified, S=SF₂ was observed at the column exit. After the run was completed, the column was heated to 100°C under a 1 sLpm N₂ flow to remove the volatile adsorbed species. 150 g of material was recovered from the column. Elemental analysis showed that nearly all of the mass gain was due to uptake of elemental S₈.

Data from additional runs using different carbons are shown in Table 1.

Table 1. S=SF₂ capacities of various carbons.

Carbon	Surface Area (m ² /g)	sL SF ₄ Purified before S=SF ₂ Breakthrough	Comments
Pacific	890	160	Some SOF ₂ , SO ₂
Norit	880	180	Some SOF ₂ , SO ₂
Barnaby Sutcliff	953	270	Little SOF ₂ , SO ₂
Westvaco	2260	50	Large amounts of SOF ₂ , SO ₂
Aldrich	621	31	Large amounts of SOF ₂ , SO ₂
Darco	441	10	Very large amounts of SOF ₂ , SO ₂

In general, the greater the amount of SOF₂ or SO₂ observed during the purification, the lower the capacity of the carbon for S=SF₂. In other words, the thiothionylfluoride

capacity of the high surface area material is inversely correlated to the amount of SOF_2 and SO_2 generated.

Example 2

Regeneration of the Pacific Carbon Capacity for $\text{S}=\text{SF}_2$

5 The run of Example 1 was repeated without removing the spent carbon from the column. 160 sL of SF_4 were purified prior to $\text{S}=\text{SF}_2$ breakthrough. The column was heated to 280°C under a flow of 0.4 sLpm air. The production of SO_2 from the oxidation of the sulfur was monitored by FT-IR. A sharp temperature spike of about $50\text{-}80^\circ\text{C}$ slowly moving down the bed indicated the sulfur- O_2 reaction zone. After the reaction zone had traversed the column, the airflow was stopped. After cooling the carbon to room temperature, SF_4 containing 8% v/v $\text{S}=\text{SF}_2$ was passed through the column in a similar manner to Example 1. $\text{S}=\text{SF}_2$ was observed to breakthrough the column after 165 sL of SF_4 was passed, showing that all of the $\text{S}=\text{SF}_2$ capacity was recovered by the air regeneration. No additional amounts of SO_2 or SOF_2 were observed over what was observed in Example 1, showing that the regeneration air did not react significantly with the activated carbon to form additional oxygenated active sites.

Additional air regeneration runs were made at 200°C and 350°C . At 200°C the production of SO_2 was slow and only about 1/3 of the $\text{S}=\text{SF}_2$ capacity was recovered. At 350°C the entire $\text{S}=\text{SF}_2$ capacity was recovered.

20 During the regeneration of the carbon, it is important not to react the carbon surface with O_2 , because this will form SF_4 -reactive sites on the regenerated carbon. In order to find the maximum regeneration temperature prior to carbon reaction, a thermogravimetric analysis of carbon was performed.

Example 3

Mass Loss of Unreacted Carbon in Air by Thermogravimetric Analysis (TGA)

During the TGA experiment, a few milligrams of Pacific activated carbon were exposed to air at various temperatures while monitoring its mass. Reaction with air is indicated by loss of mass through conversion to volatile CO_2 and CO . At 200°C , mass loss is less than $1\text{ }\mu\text{g/min}$, while at 300°C the mass loss is approximately $5\text{ }\mu\text{g/min}$. At 400°C , a mass loss of over $1000\text{ }\mu\text{g/min}$ was observed.

Example 4

Mass Loss of Reacted Carbon in Air by Thermogravimetric Analysis (TGA)

The TGA experiment of Example 3 was repeated on Pacific carbon containing deposited elemental sulfur after the purification of SF_4 . At 200°C , the mass loss is $9\text{ }\mu\text{g/min}$, while at 300°C , the mass loss is over $200\text{ }\mu\text{g/min}$.

These results show that elemental sulfur reacts approximately 40 times faster than the activated carbon. Thus, the optimum feed air temperature range for the regeneration is $250\text{--}350^\circ\text{C}$. In this range, the elemental sulfur reacts to form the volatile SO_2 , but the carbon itself is not oxidized.

The following comparative example demonstrates that not all high surface area materials can be used to remove $\text{S}=\text{SF}_2$ from SF_4 . Particularly, if the proposed catalyst is composed of metal oxide, it will react with SF_4 .

Comparative Example

Use of 13X

The system of Example 1 was used to test 136 g of Na-FAU (13X) as a catalyst for removing $\text{S}=\text{SF}_2$ from SF_4 . The 13X was activated by heating the column to 260°C over a 1 sLpm flow of N_2 for 17 hours. The column was cooled prior to running SF_4 . $5\%\text{ SF}_4$ in N_2 was flowed over the 13X at 2 sLpm . The column temperature rose to 130°C due to the heat of reaction. It is significant that while no $\text{S}=\text{SF}_2$ was observed at the column exit, neither was SF_4 . Only SO_2 and SOF_2 were observed. The SF_4 flow was stopped and the column heated to 250°C with a 1 sLpm N_2 flow to removed any adsorbed species. An X-ray diffraction

(XRD) analysis of the recovered 13X showed the zeolite framework was destroyed by exposure to the SF₄.

In view of the foregoing examples and disclosure, it should be apparent that the present invention provides a safer and more economical process for removal of S=SF₂ from SF₄. Using a high surface area material, such as activated carbon, in place of the toxic HF allows recovering nearly all of the SF₄ versus 25% losses for the HF method. Moreover, the instant invention accomplishes the desired removal with less danger to the environment.

While the invention has been described in detail and with reference to specific examples thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

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